Motor Control Blockset™

Sensorless Field-Oriented Control (FOC) of PMSM Using Renesas® Evaluation System for BLDC Motor (With RX66T CPU Card)

MATLAB®

R2024a

MathWorks®

How to Contact MathWorks

Latest news: www.mathworks.com

Sales and services: www.mathworks.com/sales_and_services

User community: www.mathworks.com/matlabcentral

Technical support: www.mathworks.com/support/contact_us

Phone: 508-647-7000

The MathWorks, Inc.
1 Apple Hill Drive
Natick, MA 01760-2098

Sensorless Field-Oriented Control (FOC) of PMSM Using Renesas® Evaluation System for BLDC Motor (With RX66T CPU Card)

Revision History

June 2024	First printing	"Release for R2024a"

Contents

1 About This Example

2 V/F (Open-Loop or Scalar) Control of PMSM Using Renesas Hardware

3 Field-Oriented Control (FOC) of PMSM Using Renesas Hardware

About This Example

Introduction

This example implements V/F (open-loop or scalar) and field-oriented control (FOC) techniques to control the speed of a three-phase permanent magnet synchronous motor (PMSM). The FOC speed control algorithm that the example implements uses the Extended EMF Observer block to obtain realtime rotor position using sensorless position estimation.

In addition to simulation of the V/F and FOC control algorithms, the example supports deployment of these algorithms on the Renesas evaluation system for BLDC motor (with RX66T CPU card).

The evaluation system for BLDC motor is a low-voltage permanent magnet synchronous motor (brushless DC motor) solution that enables you to easily evaluate your motor. The evaluation system has these features:

- Support for different CPU cards (including motor control MCUs)
- Inverter board (with 48V rating)
- Support for permanent magnet synchronous motor (brushless DC motor)
- Three-shunt current detection function
- Overcurrent protection function
- Support for USB mini B.

For more information about this evaluation system, see Evaluation System for BLDC Motor.

This example uses the RX66T CPU card (RTK0EMX870C00000BJ) along with the evaluation system for BLDC motor. For more details about this CPU card, see CPU Card for Motor Control.

In addition, the example requires an on-chip debugger board. For more information about he debugger boards, see On-chip Debuggers.

Hardware Requirements

This section lists the hardware requirements to run the example:

1. Renesas evaluation system for BLDC motor (RTK0EMX270S00020BJ) that includes these peripherals:

   - Inverter board (RTK0EM0000B10020BJ)
   - Permanent magnet synchronous motor (TG-55L-KA) with rated voltage of 24 V and rated current of 0.42 A

   For more details about this evaluation system, see Evaluation System for BLDC Motor and User's Manual for Evaluation System for BLDC Motor.
2. Renesas RX66T CPU card (RTK0EMX870C00000BJ)

   For details about this CPU card, see CPU Card for Motor Control.
3. Renesas on-chip debugger board (either one of the following):

   - E1
   - E2
   - E2Lite
   - E20

   For more information about these debugger boards, see On-chip Debuggers.
4. 24V power supply

Software Requirements

This section lists the software products from MathWorks® and Renesas that you need to simulate and run the example models on the evaluation system for BLDC motor (with RX66T CPU card).

Required MathWorks Products

To simulate the example model:

- MATLAB®
- Simulink®
- Motor Control Blockset
- Stateflow®

To generate code and deploy the example model:

- MATLAB
- Simulink
- Motor Control Blockset
- Stateflow
- Embedded Coder®
- Simulink Coder™
- MATLAB Coder

Required Renesas Products

- CS+ (an integrated development environment (IDE) for Renesas MCUs)

  For more details about this software, see CS+.

Contents of Downloaded ZIP Folder

The ZIP folder that you downloaded from the GitHub® repository, includes:

1 MATLAB project package for V/F and FOC control algorithms, which includes the following files and folders:

Folder Name	Description
code	Contains generated code (if any).
components	Contains Simulink model components for V/F and FOC control algorithms.
data	Contains Simulink data dictionary file (motorControlData.sldd).
model	Contains Simulink models for V/F and FOC algorithms that support both simulation and code generation.
resources	Contains MATLAB project resource data and logs.
script	Contains initialization and utility scripts to use the Simulink models.
shortcuts	Contains shortcut utility scripts for the MATLAB project window.
work	Contains any additional data or utility files (if any).

File Name	Description
RX66TDemo.prj	File that launches the MATLAB project window.

2 Driver package for the evaluation system for BLDC motor (with RX66T CPU card), which includes the following folder:

Folder Name	Description
csPlusProject	Contains the control algorithm code along with driver package for the evaluation system for BLDC motor (with RX66T CPU card). The software CS+ uses this folder to launch the Renesas hardware project for the evaluation system for BLDC motor (with RX66T CPU card). The MotorControlDemo\genCode directory available inside this folder contains the control algorithm code generated by the MATLAB project window.

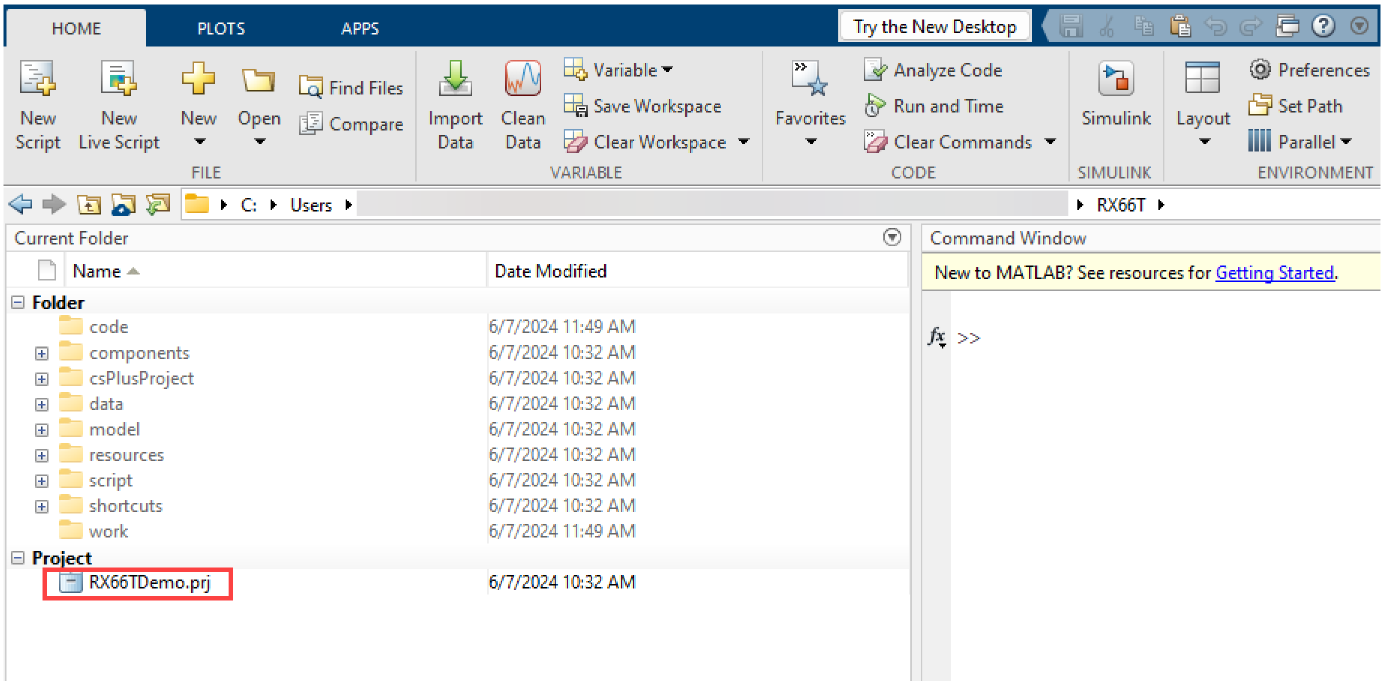
2

V/F (Open-Loop or Scalar) Control of PMSM Using Renesas Hardware

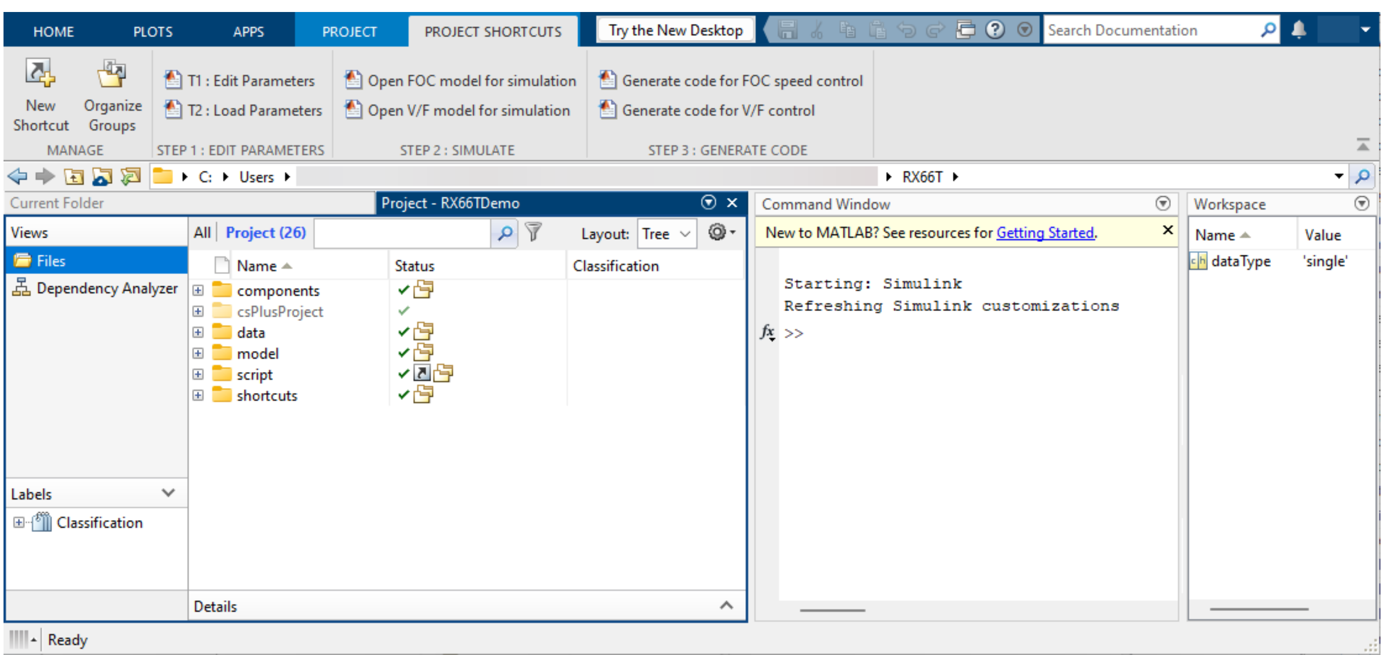
Open MATLAB Project

Follow these steps to open the MATLAB project associated with this example:

1. Unzip the `RX66T.zip` folder that you downloaded from the GitHub repository.
2. Open MATLAB and navigate to the folder you unzipped in step 1.



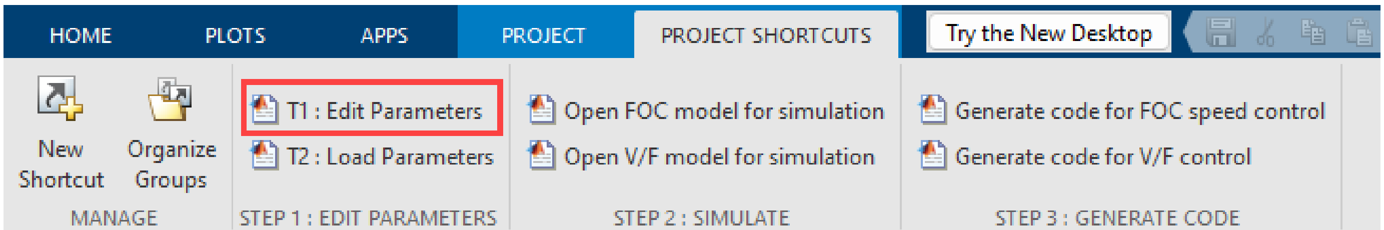
3. Double-click the file `RX66TDemo.prj` to open the following MATLAB project window.



Update Motor and Inverter Parameters

The prerequisite to simulating or deploying the Simulink model containing V/F control algorithm is to edit the motor and inverter parameters and load them to MATLAB base workspace. Follow these steps to update and load the parameters:

1 In the **Project Shortcuts** tab of the MATLAB project window, click the **T1: Edit Parameters** shortcut button to open the model initialization script `EnterParameters.m`.



The Simulink model uses this script to obtain the motor, inverter, and other parameter values, which it uses to compute the derived parameters.

2 Update the following sections of the model initialization script `EnterParameters.m`:

- **Control Loop Frequencies**
- **Inverter Parameters**
- **Motor Parameters**

EnterParameters.m

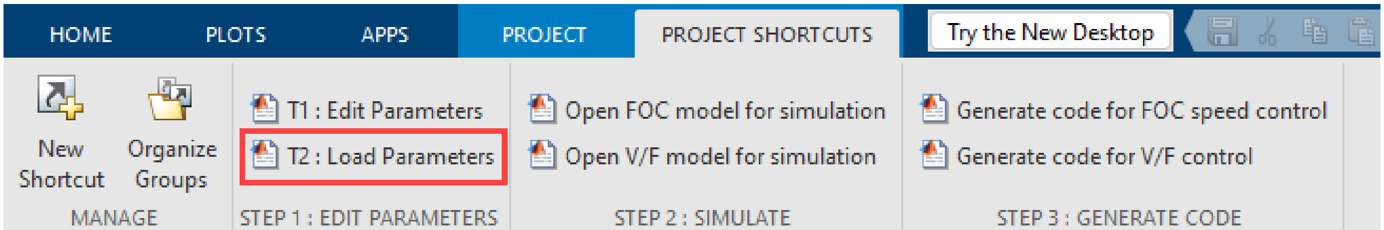
```
% Copyright 2024 The MathWorks, Inc.

%% Control loop frequencies
fCurrentControl         = 20e3;     % Hz
fSpeedControl           = fCurrentControl/10;      % Hz

target.PWM_frequency    = 20e3;     % Hz          % The frequency configuration must be done in driver code too

%% Inverter Parameters
inverter.V_dc           = 24;       % V
inverter.ISenseMax      = 12.5;     % A           % Maximum current sensed by inverter
inverter.R_board        = 0.0033;   % ohm         % Rds_ON + Rshunt/3
inverter.ISenseGainFactor = -1;     %

%% Motor Parameters
pmsm.p                  = 2;        %             % Pole pairs
pmsm.I_rated            = 0.42;     % A
pmsm.N_rated            = 3500;     % RPM
pmsm.T_rated            = 0.1;      % Nm
pmsm.QEPSlits           = 1000;     %             % Quadrature encoder slits
pmsm.Rs                 = 8.5;      % ohm
pmsm.Ld                 = 0.0045;   % H
pmsm.Lq                 = 0.0045;   % H
pmsm.Ke                 = 7.83;     % Vpk_LL/kRPM
pmsm.J                  = 2.8e-6;   % Kg-m2
pmsm.B                  = 8e-5;     % Kg-m2/s
pmsm.V_boost            = 0.4;      % PU volt

%% Sensor selection
sensor = 'EEMF';                    % 'Encoder' , 'EEMF'

%% Derived Parameters
T_pwm = 1/target.PWM_frequency;
Ts = 1/fCurrentControl;
Ts_speed = 1/fSpeedControl;
Ts_motor = Ts/2;

Ts_SerialOut = 0.1;                               % Required only for UART

pmsm.FluxPM   = (pmsm.Ke)/(sqrt(3)*2*pi*1000*pmsm.p/60);
pmsm.N_base   = mcb_getBaseSpeed(pmsm,inverter);
PU_System     = mcb_SetPUSystem(pmsm,inverter);
PI_params     = mcb_SetControllerParameters(pmsm,inverter,PU_System,T_pwm,Ts,Ts_speed);

% Create copies for EEMF block as the parameters are not tunable
```

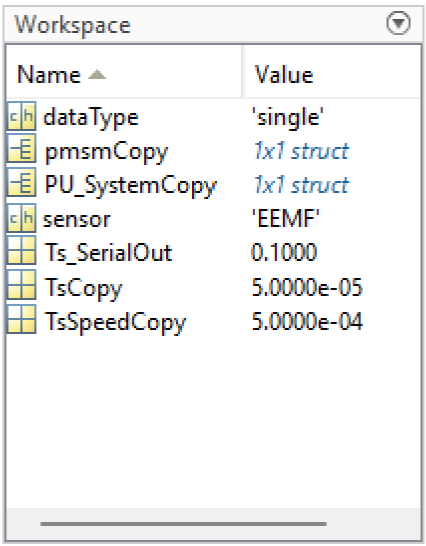
3 Click **Save** to save the file `EnterParameters.m`.

4 Switch to the MATLAB project window and navigate to the **Project Shortcuts** tab.

5 Click the **T2: Load Parameters** shortcut button to:

- Compute derived parameters using the data available in the model initialization script.
- Update all parameters to the Simulink data dictionary `motorControlData.sldd`.
- Load necessary parameters from Simulink data dictionary to the MATLAB base workspace.



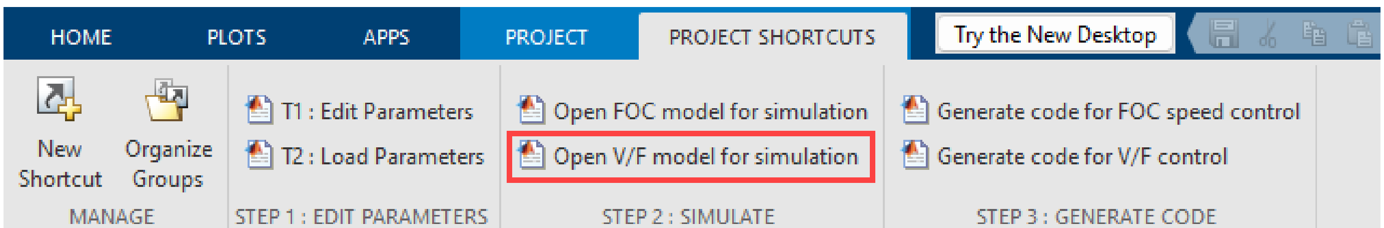


Note The shortcut **T2: Load Parameters** loads only the necessary parameters to the base workspace. The Simulink model reads the other parameters directly from the Simulink data dictionary.

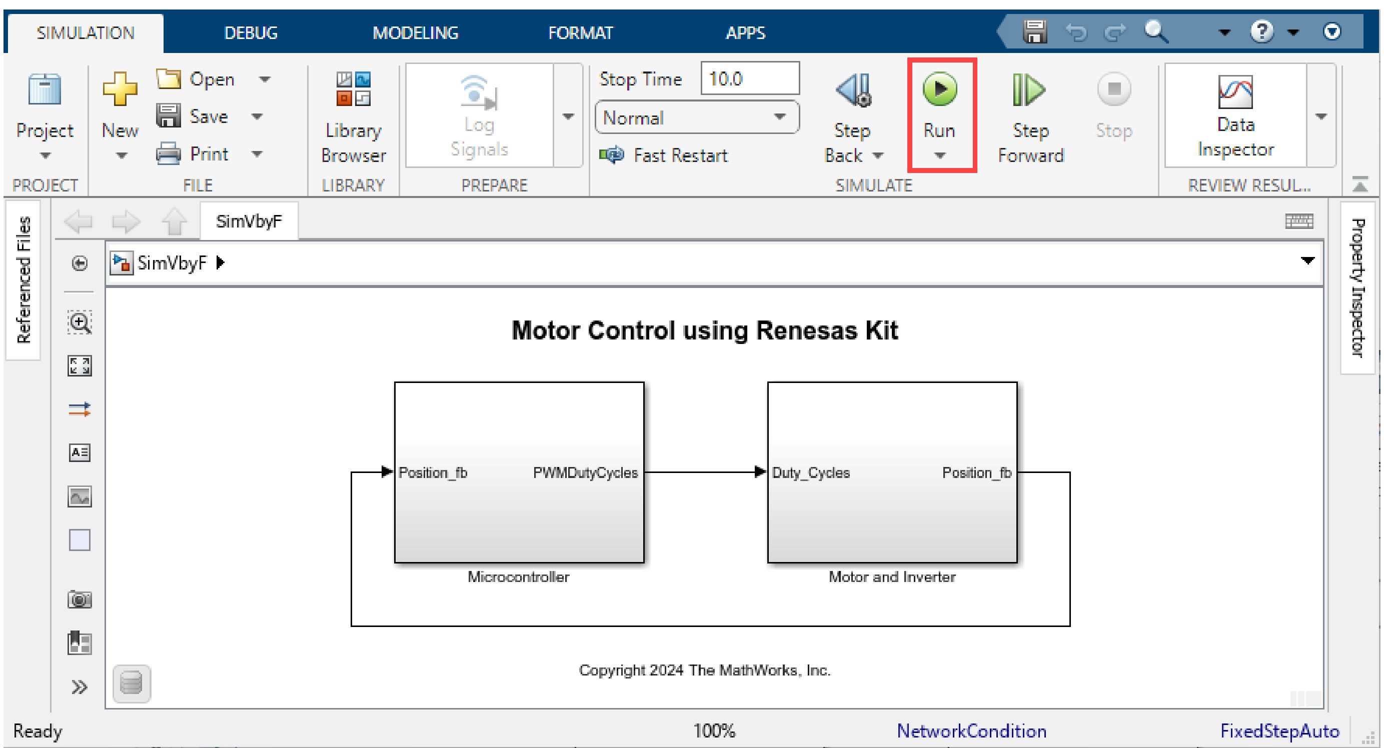
Simulate Model Containing V/F Control Algorithm

This example supports simulation. Follow these steps to simulate the Simulink model containing the V/F control algorithm.

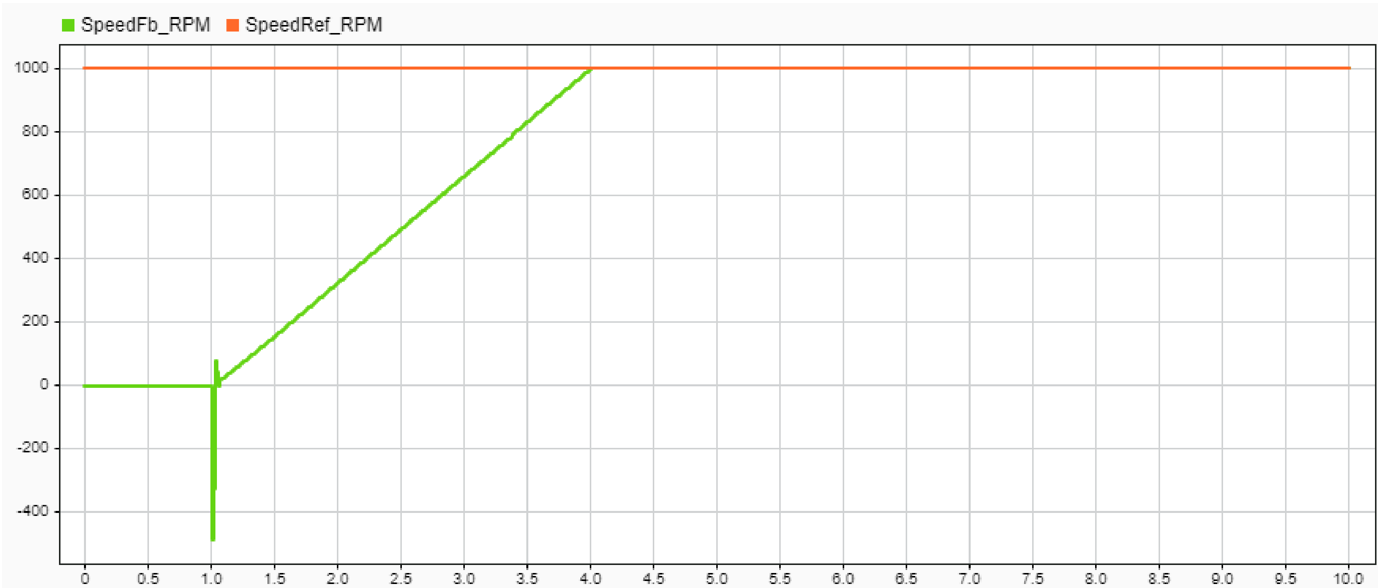
1. Ensure that you edit the motor and inverter parameters and load them to the MATLAB base workspace. For details, see the section Update Motor and Inverter Parameters.
2. In the **Project Shortcuts** tab of the MATLAB project window, click the **Open V/F model for simulation** shortcut button to open the Simulink model `SimVbyF.slx` containing the V/F control algorithm.



3. Click **Run** on the **Simulation** tab to simulate the model.



4. Click **Data Inspector** on the **Simulation** tab to view and analyze the simulation results.

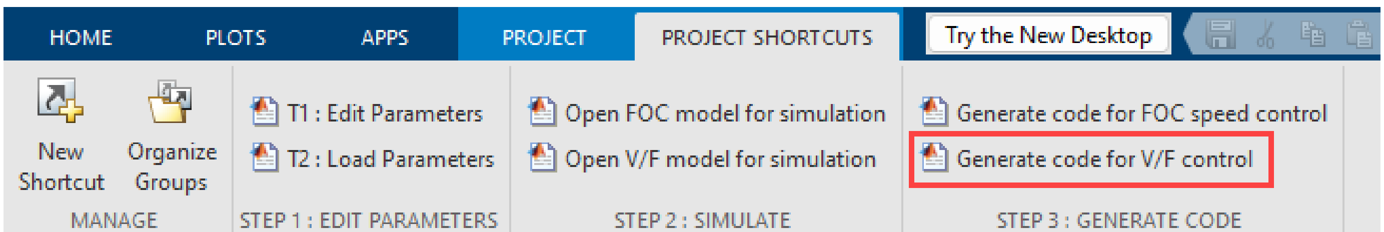

SpeedFb_RPM
SpeedRef_RPM
1000
800
600
400
200
0
-200
-400
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0

Generate Code for V/F Control Algorithm

This section explains how to use the Simulink model `SimVbyF.slx` to generate code for the V/F control algorithm.

Follow these steps to generate the code:

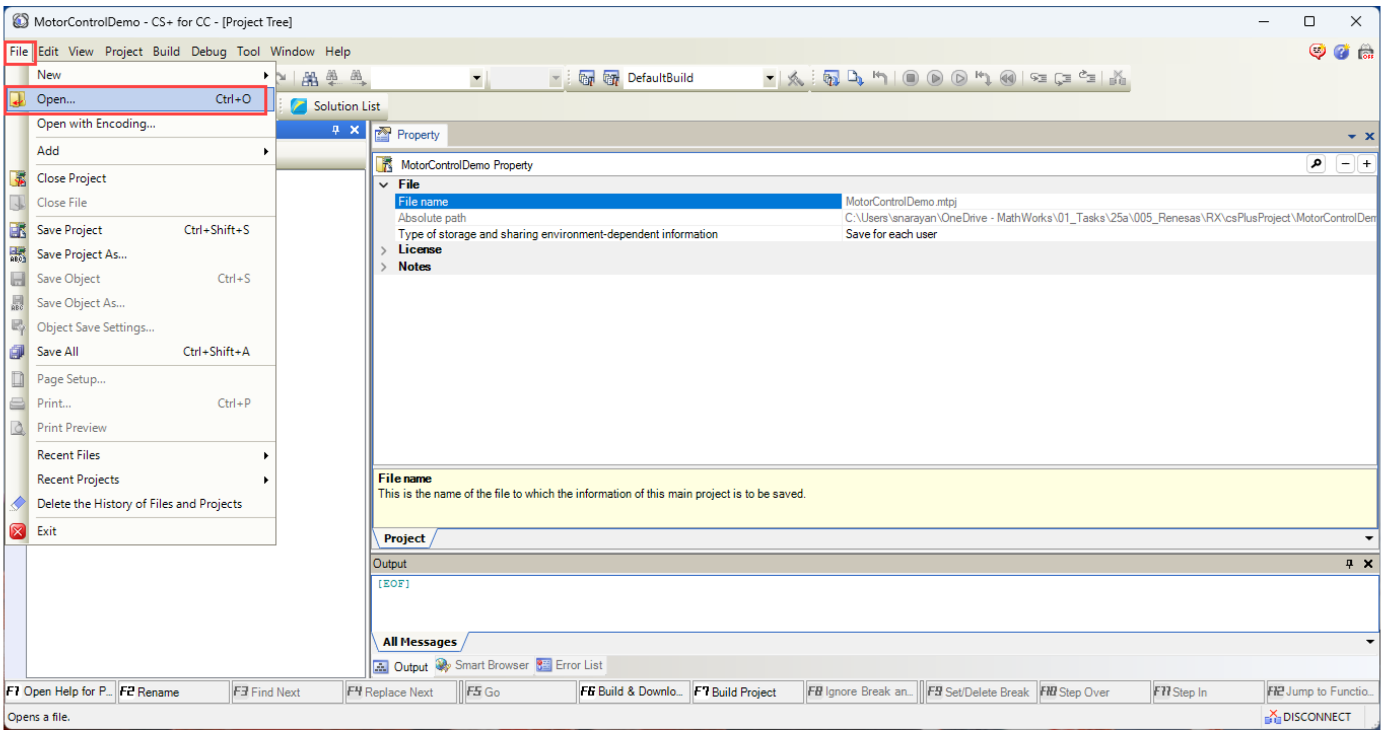
1. Simulate the model `SimVbyF.slx` and observe the simulation results. For details, see the section Simulate Model Containing V/F Control Algorithm.
2. Click the **Generate code for V/F control** shortcut button to build the model `SimVbyF.slx` as well as generate and save code inside `MotorControlDemo\genCode` directory available in the `csPlusProject` folder.

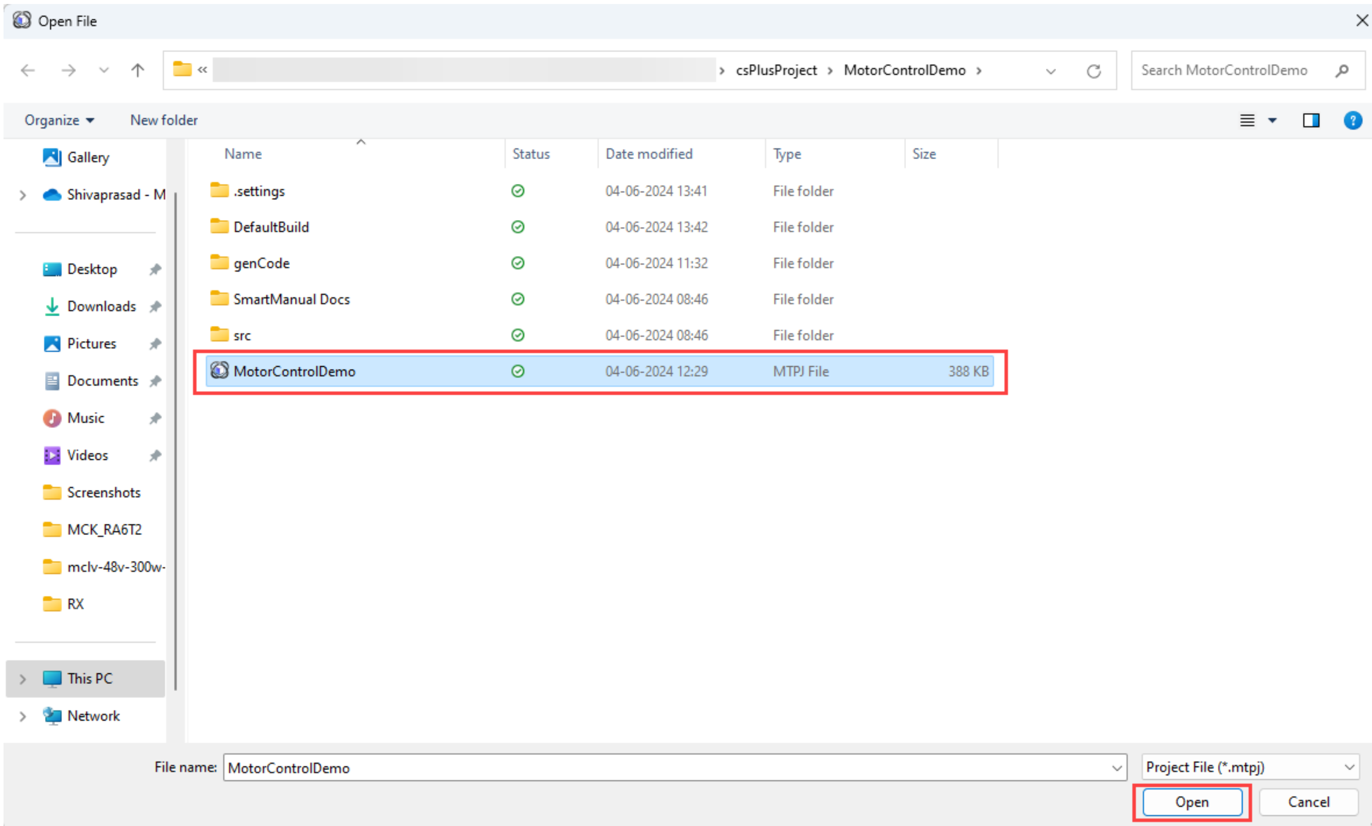


Deploy V/F Control Algorithm Code and Drivers to Hardware

Follow these steps to deploy the generated V/F control algorithm code along with hardware drivers to the evaluation system for BLDC motor (with RX66T CPU card) using the software CS+:

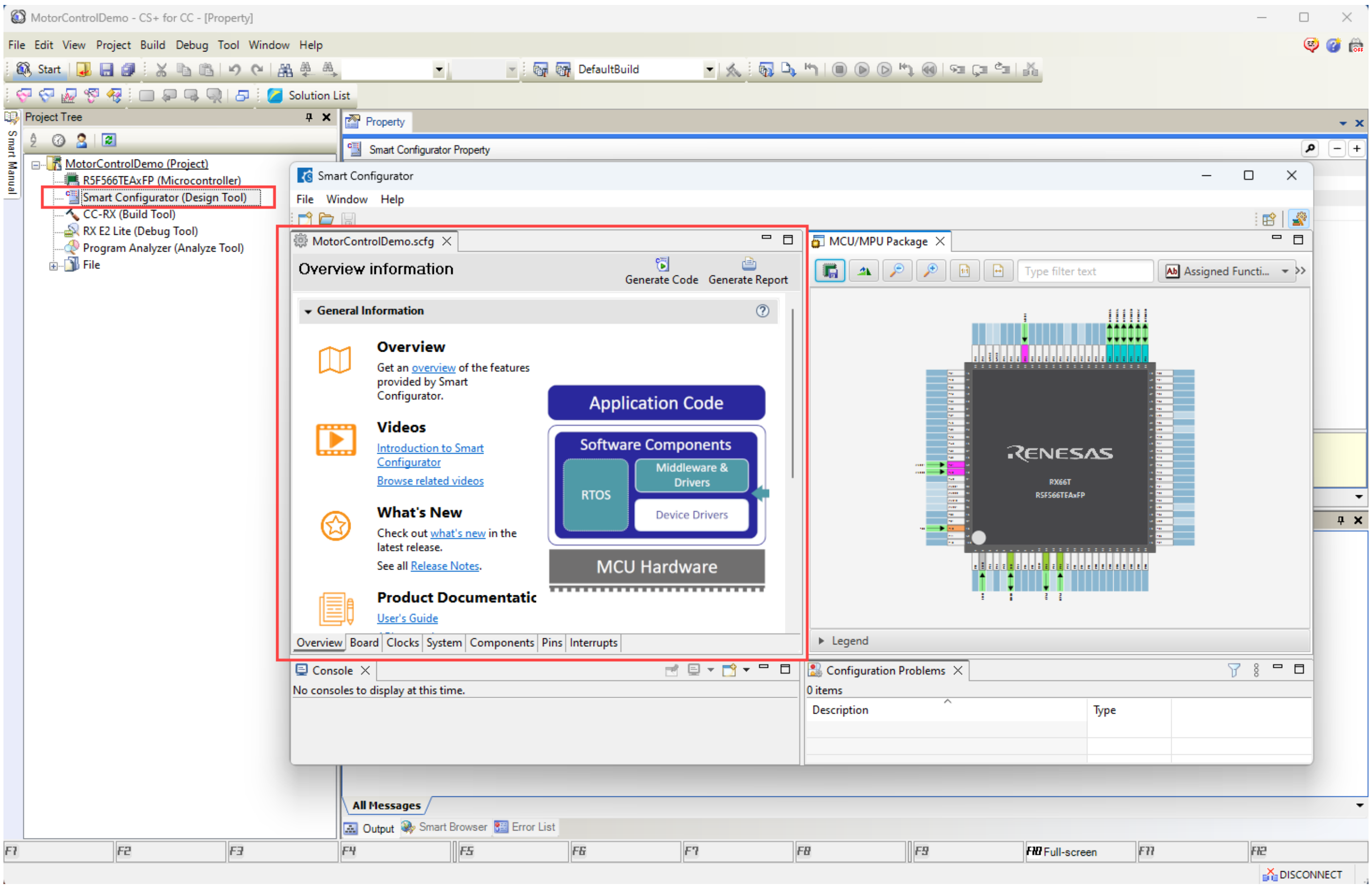
1. Complete the hardware connections between the evaluation system for BLDC motor, RX66T CPU card, and debugger board. Connect the evaluation system to your computer. For details, see User's Manual for Evaluation System for BLDC Motor.
2. Open the CS+ software.
3. Use the menu **File** > **Open** to navigate to the folder `csPlusProject\MotorControlDemo`, and select the file `MotorControlDemo.mtpj`.





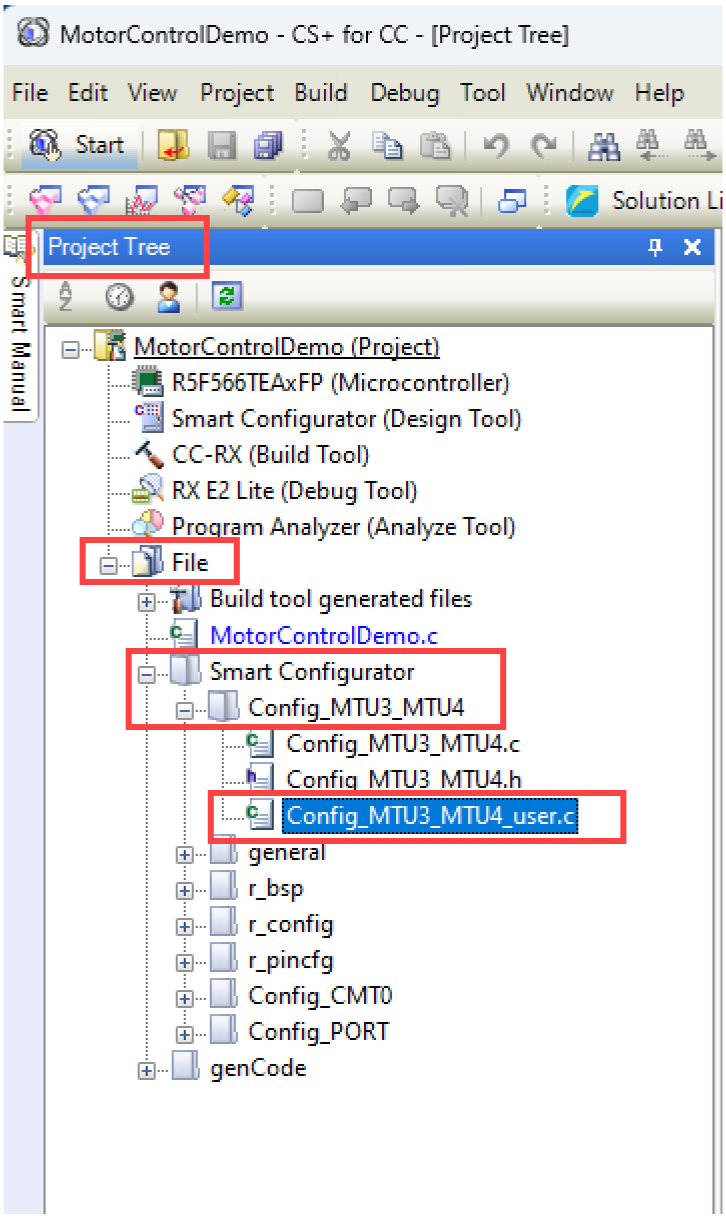
Click **Open** to open the Renesas hardware project for the evaluation system for BLDC motor (with RX66T CPU card) in the **Project Tree** panel of the CS+ software interface.

4 You can double-click the option **Smart Configurator (Design Tool)** to view the driver package configuration for the evaluation system for BLDC motor (with RX66T CPU card) as shown in the following figure.

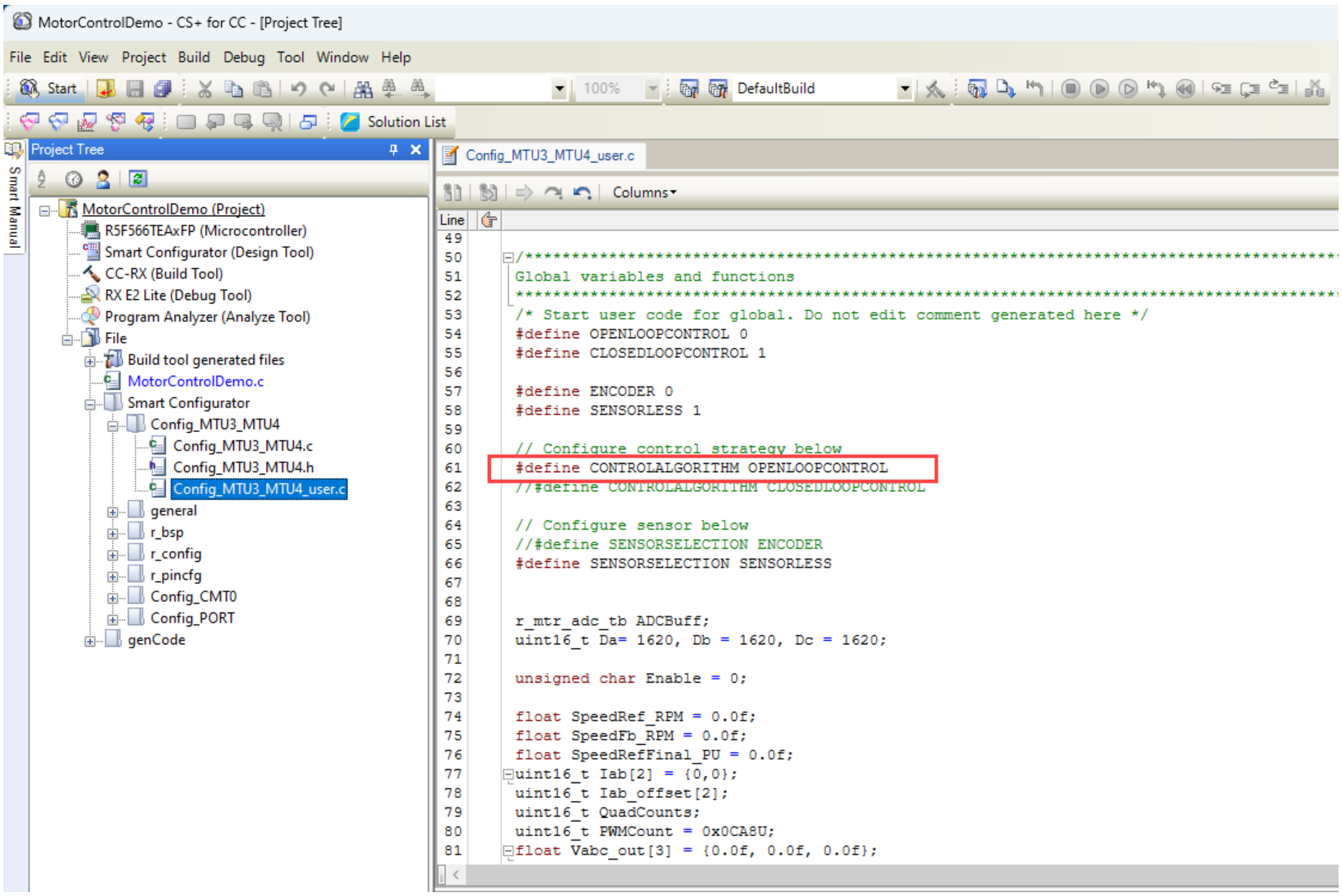


5 In the **Project Tree** panel, expand the folder `File` to open its contents.

Navigate to the folder `Smart Configurator/Config_MTU3_MTU4` and double-click the file `Config_MTU3_MTU4_user.c` to open it in the editor.

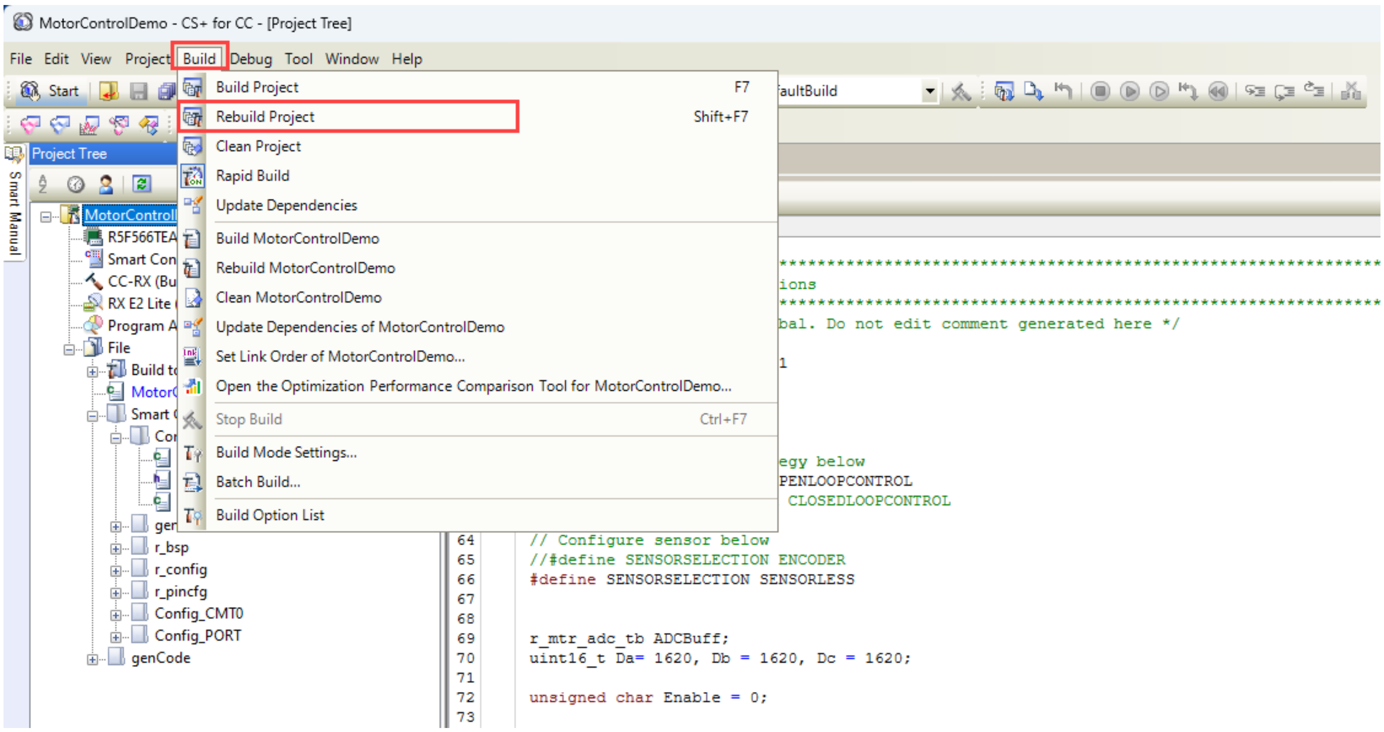


6 Set the macro `CONTROLALGORITHM` to `OPENLOOPCONTROL` as shown in the following figure.

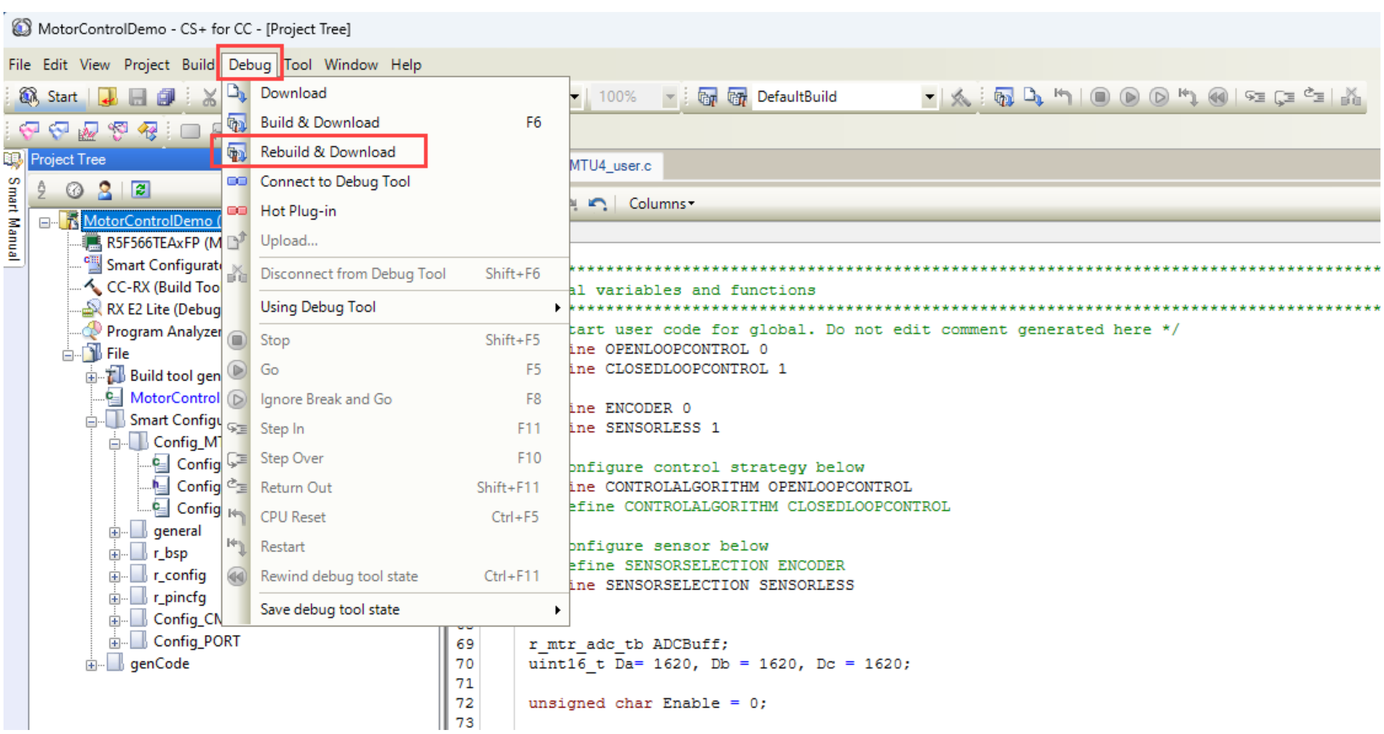


Save the file `Config_MTU3_MTU4_user.c`.

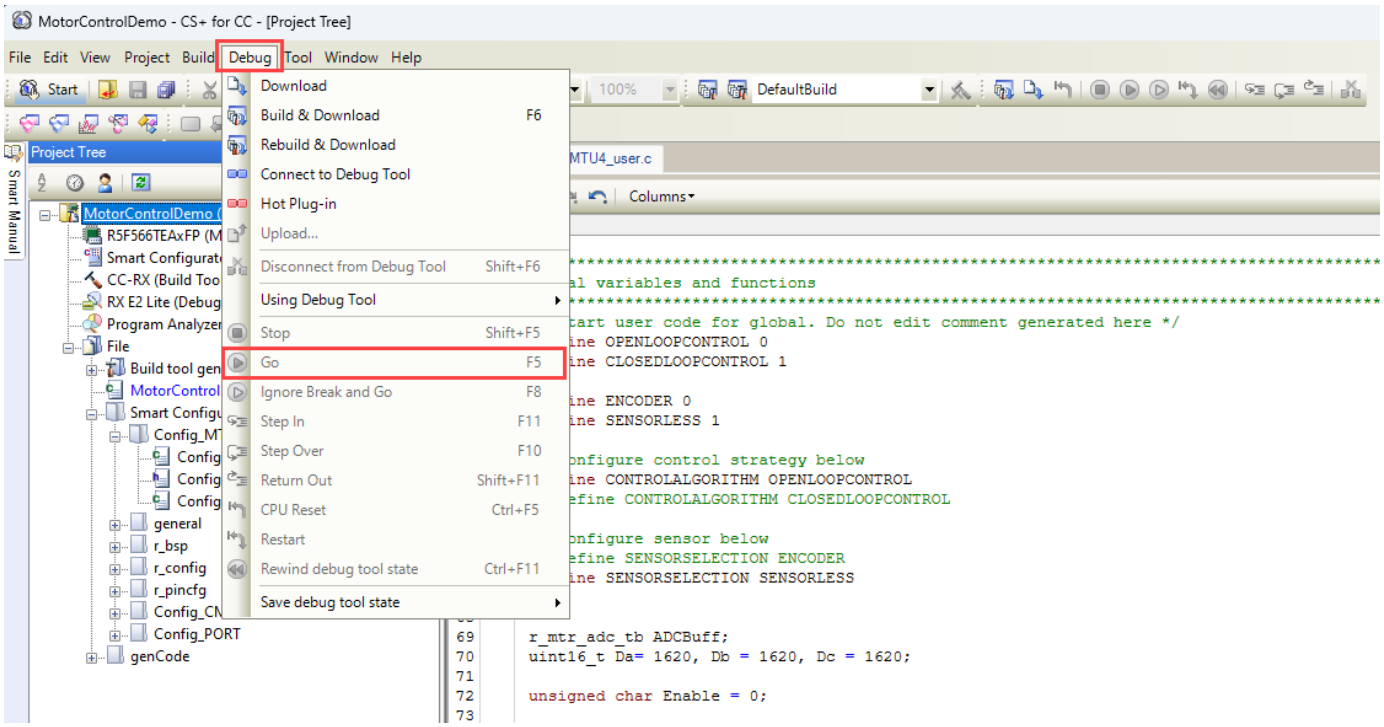
7 In the CS+ software interface, click **Build** > **Rebuild Project** to build the object code for the entire Renesas hardware project containing V/F control algorithm and hardware drivers.



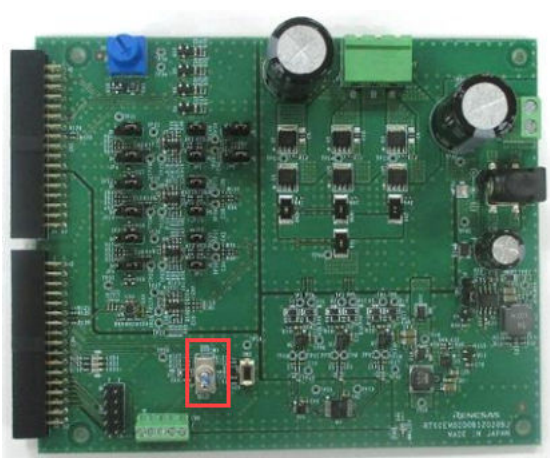
8 In the CS+ software interface, click **Debug** > **Rebuild & Download** to deploy the object code for the V/F control algorithm and hardware drivers to the evaluation system for BLDC motor (with RX66T CPU card).



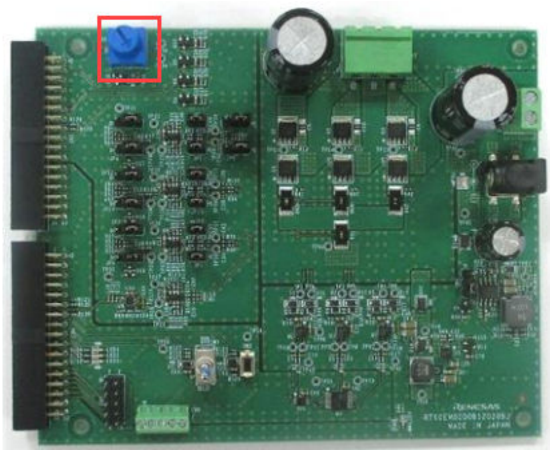
9 In the CS+ software interface, click **Debug** > **Go** to start running the deployed code.



10 On the inverter board, turn the toggle switch to ON position to start running the motor.



11 During code execution on hardware, you can use the following pot (or dial) on the inverter board to change the reference speed for the V/F control algorithm.



12 To stop running the motor turn the toggle switch on the inverter board to OFF position.

Note

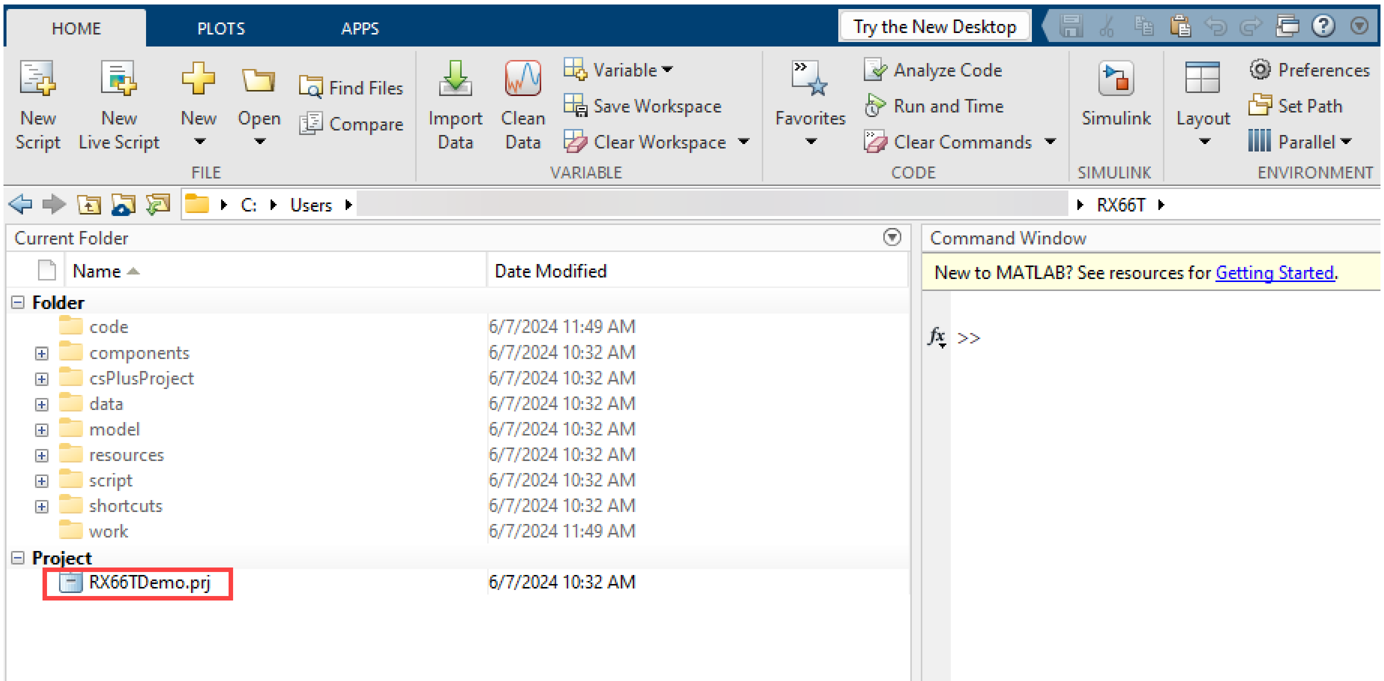
- You can safely disconnect the evaluation system for BLDC motor (with RX66T CPU card) from the computer after completing step 9.
- After you disconnect the evaluation system from the computer, the deployed code stays on the evaluation system and resumes execution even when you disconnect and reconnect the hardware power supply.

Field-Oriented Control (FOC) of PMSM Using Renesas Hardware

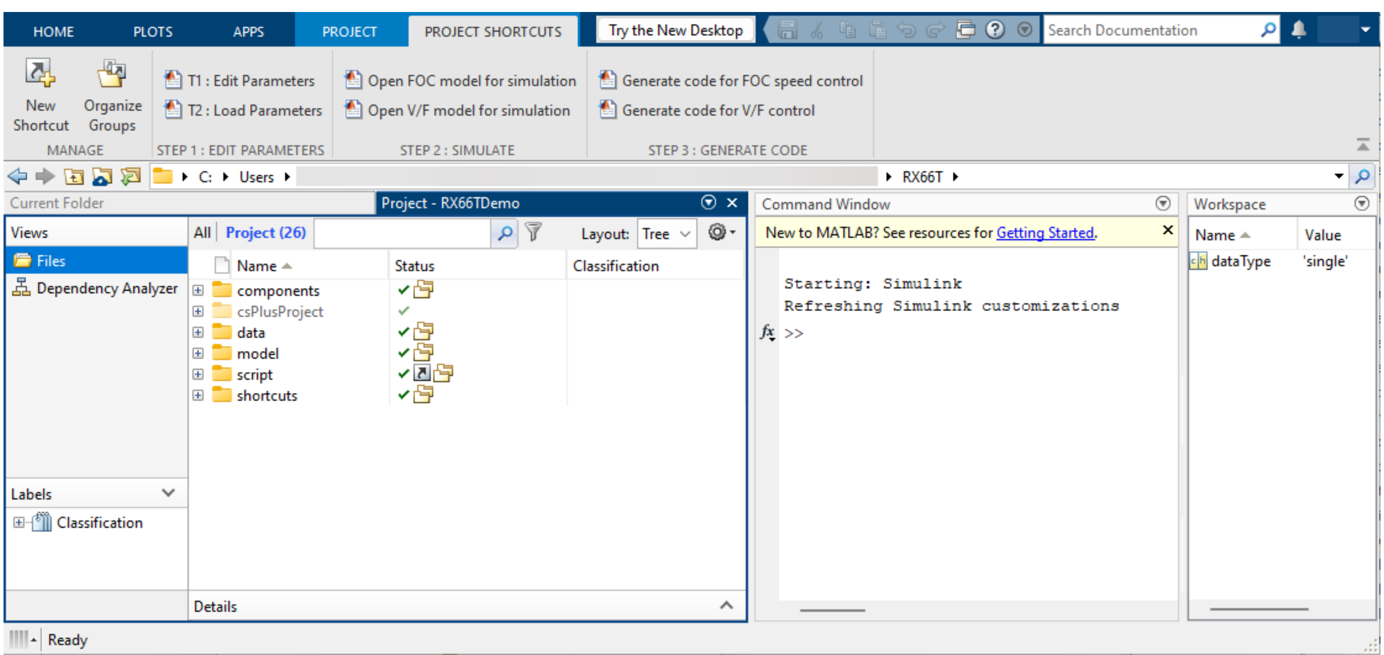
Open MATLAB Project

Follow these steps to open the MATLAB project associated with this example:

1. Unzip the `RX66T.zip` folder that you downloaded from the GitHub repository.
2. Open MATLAB and navigate to the folder you unzipped in step 1.



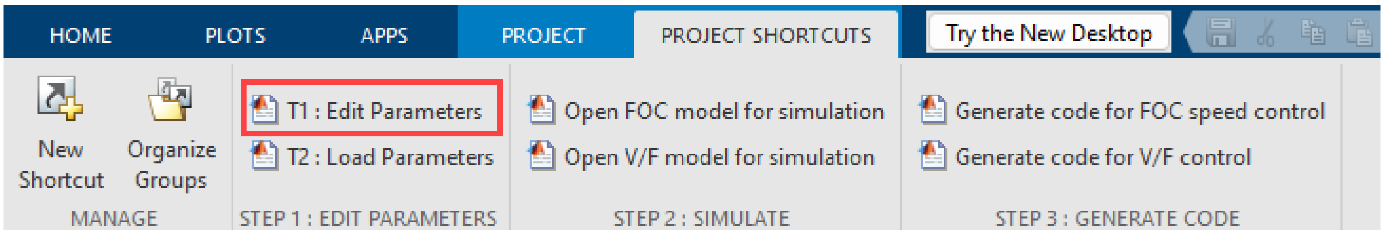
3. Double-click the file `RX66TDemo.prj` to open the following MATLAB project window.



Update Motor and Inverter Parameters

The prerequisite to simulating or deploying the Simulink model containing FOC algorithm is to edit the motor and inverter parameters and load them to MATLAB base workspace. Follow these steps to update and load the parameters:

1. In the **Project Shortcuts** tab of the MATLAB project window, click the **T1: Edit Parameters** shortcut button to open the model initialization script `EnterParameters.m`.



   The Simulink model uses this script to obtain the motor, inverter, and other parameter values, which it uses to compute the derived parameters.

2. Update the following sections of the model initialization script `EnterParameters.m`:

   - **Control Loop Frequencies**
   - **Inverter Parameters**
   - **Motor Parameters**

EnterParameters.m

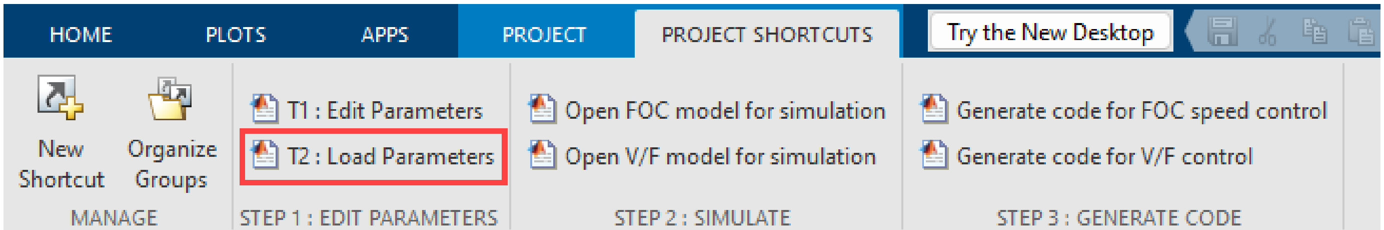
```
% Copyright 2024 The MathWorks, Inc.

%% Control loop frequencies
fCurrentControl          = 20e3;     % Hz
fSpeedControl            = fCurrentControl/10;      % Hz

target.PWM_frequency     = 20e3;     % Hz          % The frequency configuration must be done in driver code too

%% Inverter Parameters
inverter.V_dc            = 24;       % V
inverter.ISenseMax       = 12.5;     % A           % Maximum current sensed by inverter
inverter.R_board         = 0.0033;   % ohm         % Rds_ON + Rshunt/3
inverter.ISenseGainFactor = -1;      %

%% Motor Parameters
pmsm.p                   = 2;        %             % Pole pairs
pmsm.I_rated             = 0.42;     % A
pmsm.N_rated             = 3500;     % RPM
pmsm.T_rated             = 0.1;      % Nm
pmsm.QEPSlits            = 1000;     %             % Quadrature encoder slits
pmsm.Rs                  = 8.5;      % ohm
pmsm.Ld                  = 0.0045;   % H
pmsm.Lq                  = 0.0045;   % H
pmsm.Ke                  = 7.83;     % Vpk_LL/kRPM
pmsm.J                   = 2.8e-6;   % Kg-m2
pmsm.B                   = 8e-5;     % Kg-m2/s
pmsm.V_boost             = 0.4;      % PU volt

%% Sensor selection
sensor = 'EEMF';                     % 'Encoder' , 'EEMF'

%% Derived Parameters
T_pwm = 1/target.PWM_frequency;
Ts = 1/fCurrentControl;
Ts_speed = 1/fSpeedControl;
Ts_motor = Ts/2;

Ts_SerialOut = 0.1;                                % Required only for UART

pmsm.FluxPM    = (pmsm.Ke)/(sqrt(3)*2*pi*1000*pmsm.p/60);
pmsm.N_base    = mcb_getBaseSpeed(pmsm,inverter);
PU_System      = mcb_SetPUSystem(pmsm,inverter);
PI_params      = mcb_SetControllerParameters(pmsm,inverter,PU_System,T_pwm,Ts,Ts_speed);

% Create copies for EEMF block as the parameters are not tunable
```

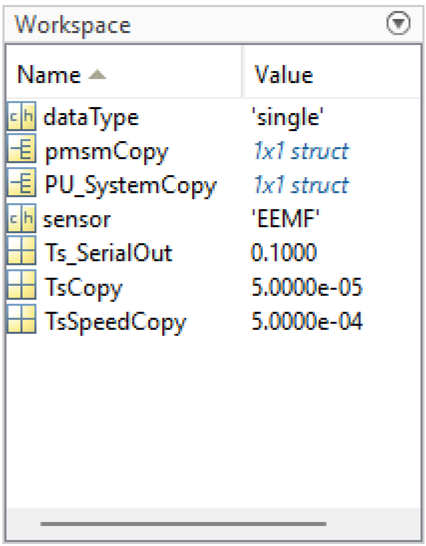
3 Click **Save** to save the file `EnterParameters.m`.

4 Switch to the MATLAB project window and navigate to the **Project Shortcuts** tab.

5 Click the **T2: Load Parameters** shortcut button to:

- Compute derived parameters using the data available in the model initialization script.
- Update all parameters to the Simulink data dictionary `motorControlData.sldd`.
- Load necessary parameters from Simulink data dictionary to the MATLAB base workspace.



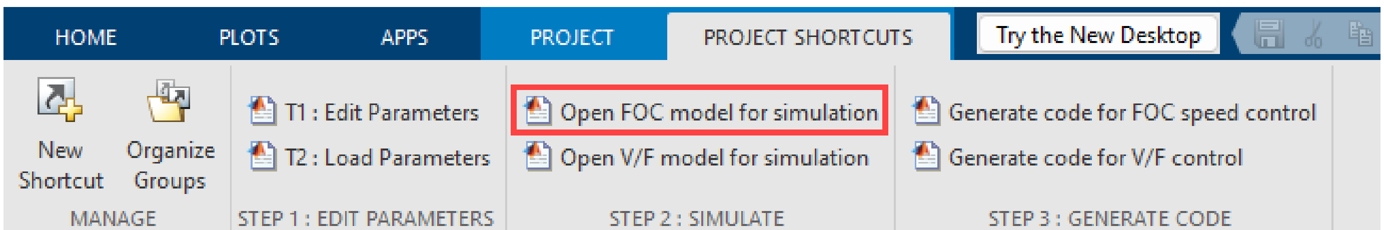


Note The shortcut **T2: Load Parameters** loads only the necessary parameters to the base workspace. The Simulink model reads the other parameters directly from the Simulink data dictionary.

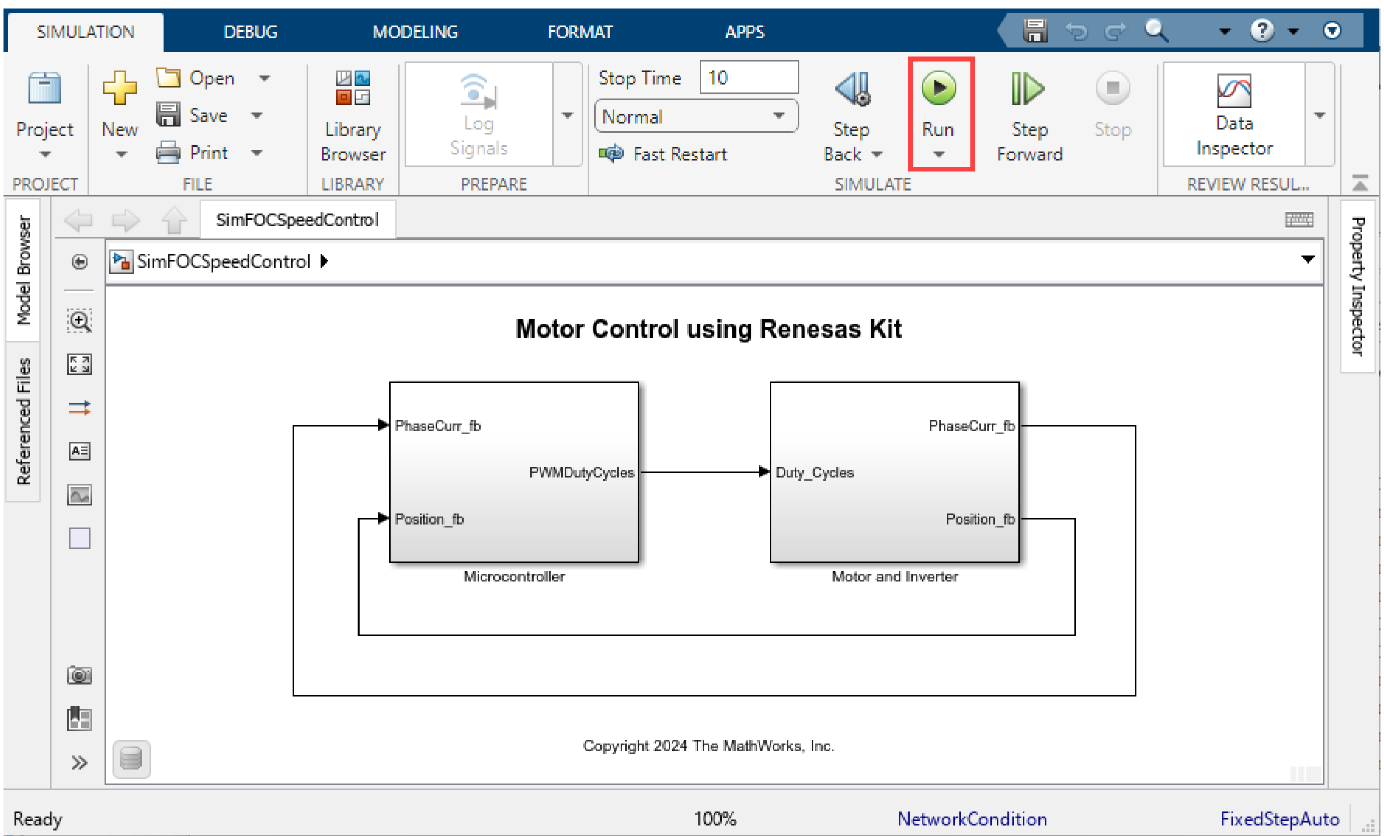
Simulate Model Containing FOC Algorithm

This example supports simulation. Follow these steps to simulate the Simulink model containing the FOC speed control algorithm.

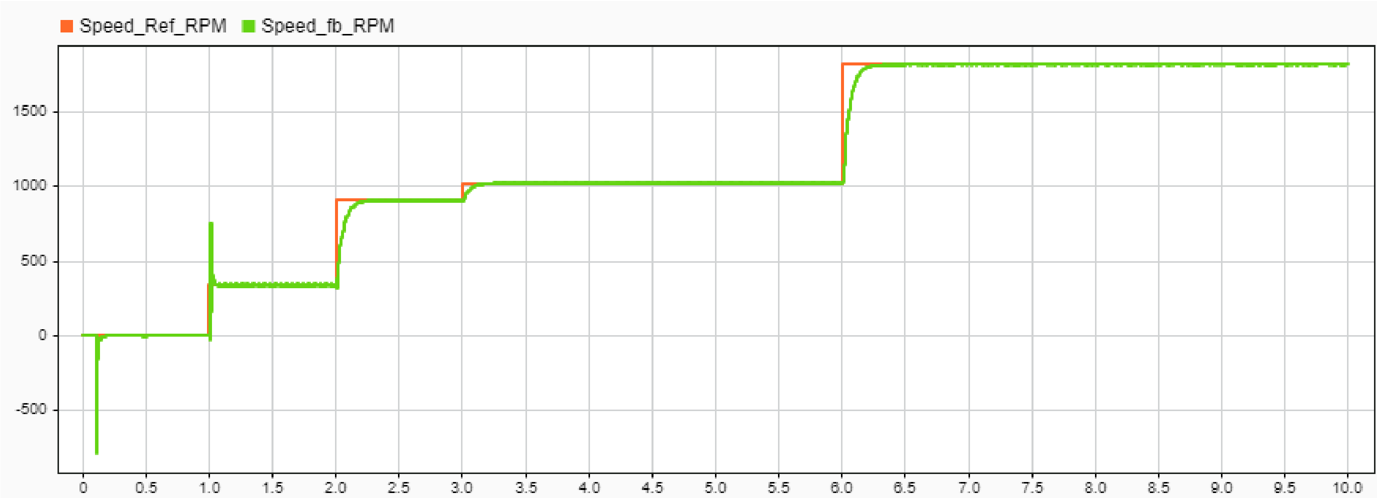
1. Ensure that you edit the motor and inverter parameters and load them to the MATLAB base workspace. For details, see the section Update Motor and Inverter Parameters.
2. In the **Project Shortcuts** tab of the MATLAB project window, click the **Open FOC model for simulation** shortcut button to open the Simulink model `SimFOCSpeedControl.slx` containing the FOC speed control algorithm.



3. Click **Run** on the **Simulation** tab to simulate the model.



4. Click **Data Inspector** on the **Simulation** tab to view and analyze the simulation results.



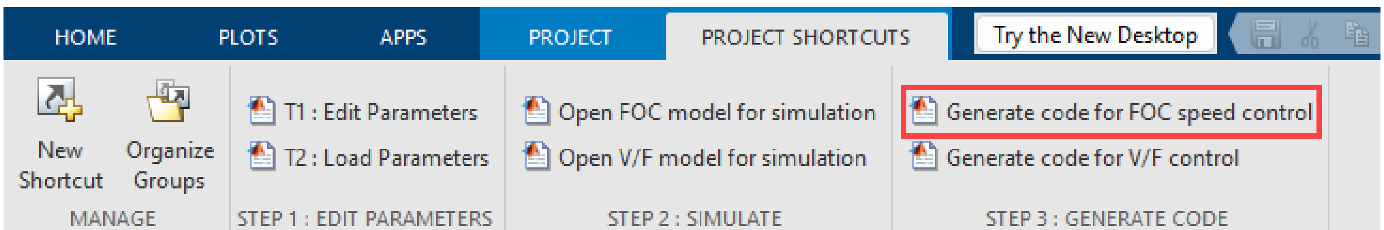
Speed_Ref_RPM
Speed_fb_RPM
1500
1000
500
0
-500
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0

Generate Code for FOC Algorithm

This section explains how to use the Simulink model `SimFOCSpeedControl.slx` to generate code for the FOC speed control algorithm.

Follow these steps to generate the code:

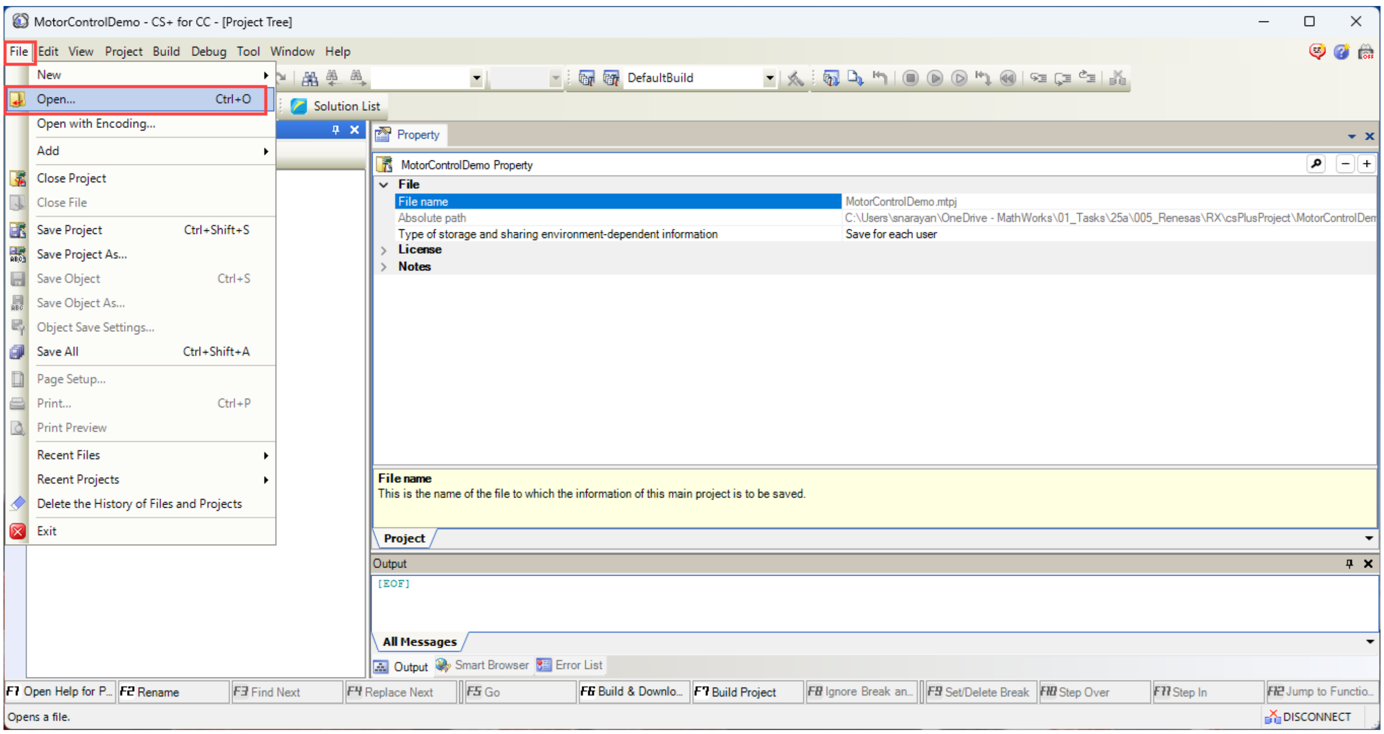
1. Simulate the model `SimFOCSpeedControl.slx` and observe the simulation results. For details, see the section Simulate Model Containing FOC Algorithm.
2. Click the **Generate code for FOC speed control** shortcut button to build the model `SimFOCSpeedControl.slx` as well as generate and save code inside `MotorControlDemo\genCode` directory available in the `csPlusProject` folder.

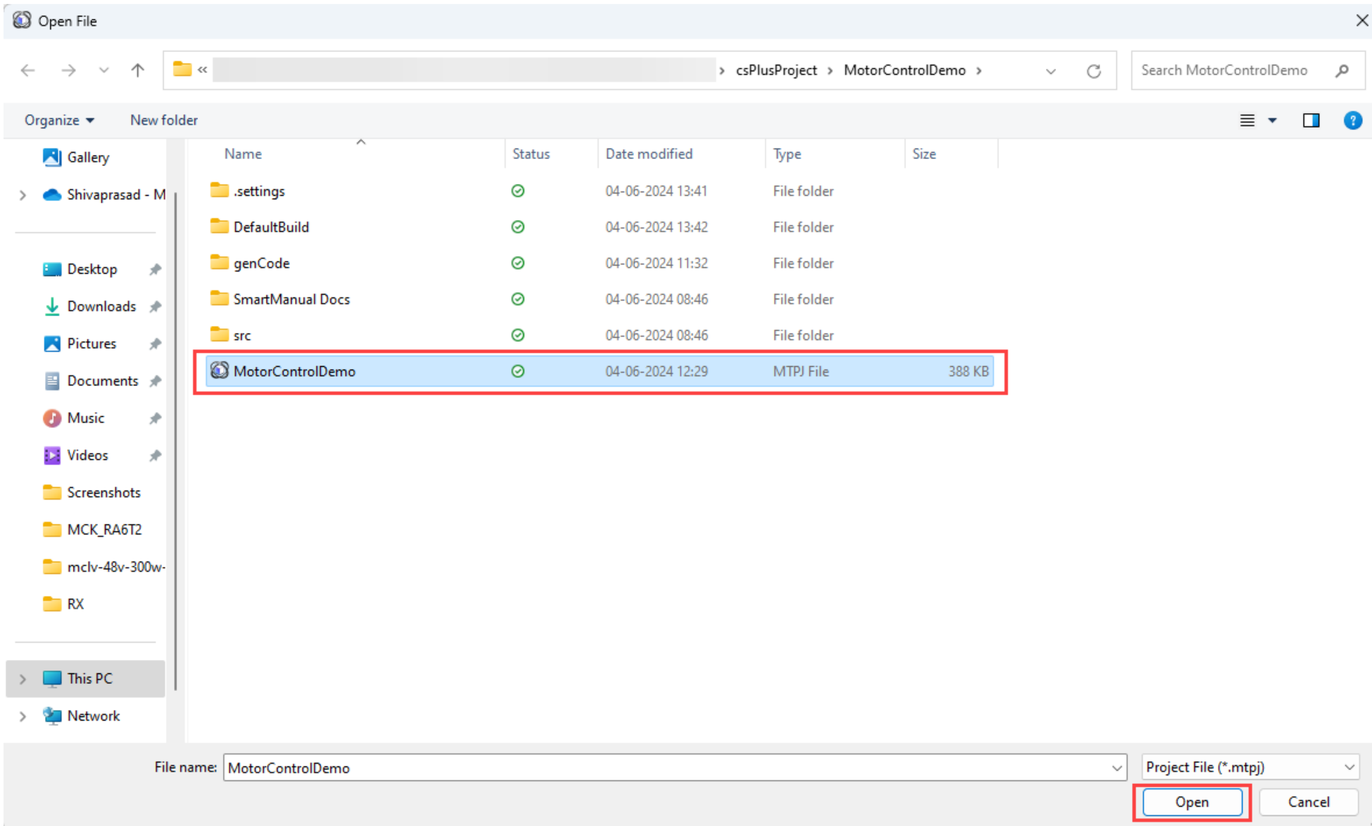


Deploy FOC Algorithm Code and Drivers to Hardware

Follow these steps to deploy the generated FOC speed control algorithm code along with hardware drivers to the evaluation system for BLDC motor (with RX66T CPU card) using the software CS+:

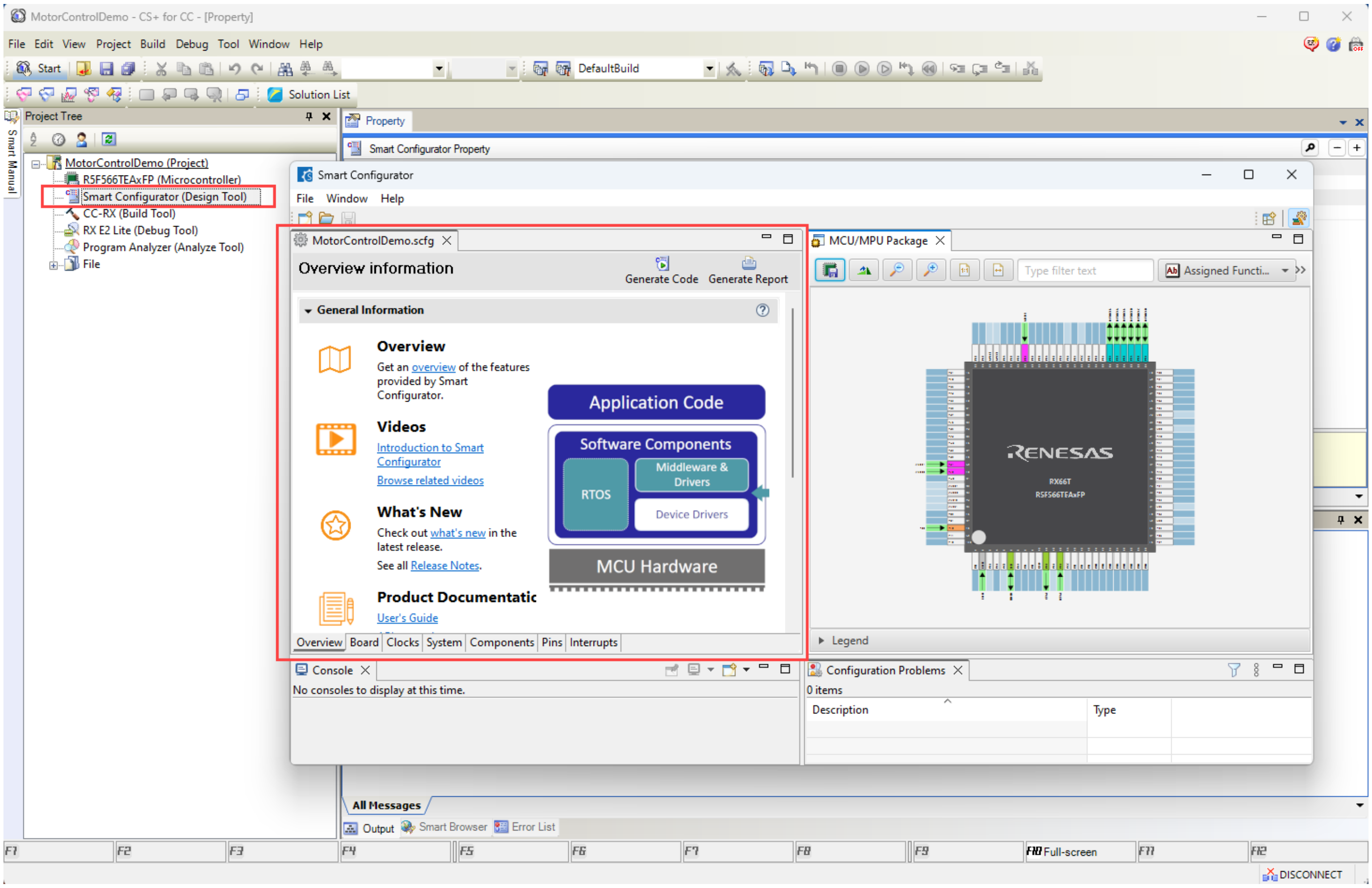
1. Complete the hardware connections between the evaluation system for BLDC motor, RX66T CPU card, and debugger board. Connect the evaluation system to your computer. For details, see User's Manual for Evaluation System for BLDC Motor.
2. Open the CS+ software.
3. Use the menu **File** > **Open** to navigate to the folder `csPlusProject\MotorControlDemo`, and select the file `MotorControlDemo.mtpj`.





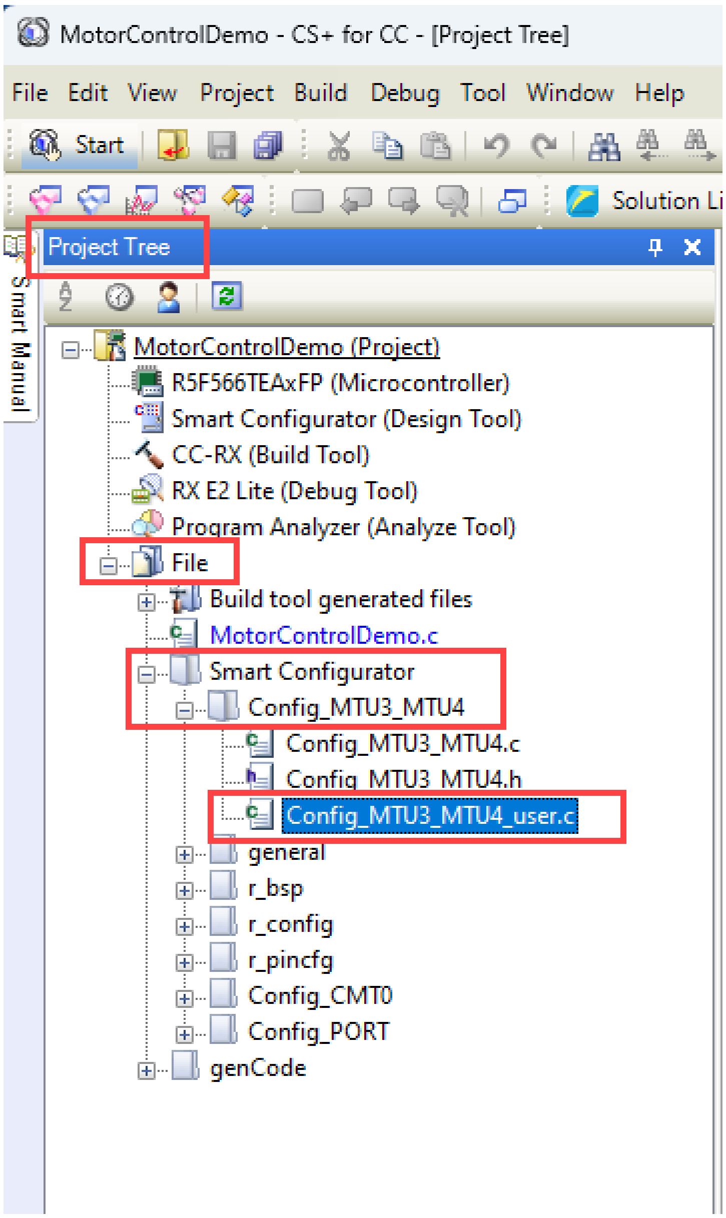
Click **Open** to open the Renesas hardware project for the evaluation system for BLDC motor (with RX66T CPU card) in the **Project Tree** panel of the CS+ software interface.

4 You can double-click the option **Smart Configurator (Design Tool)** to view the driver package configuration for the evaluation system for BLDC motor (with RX66T CPU card) as shown in the following figure.

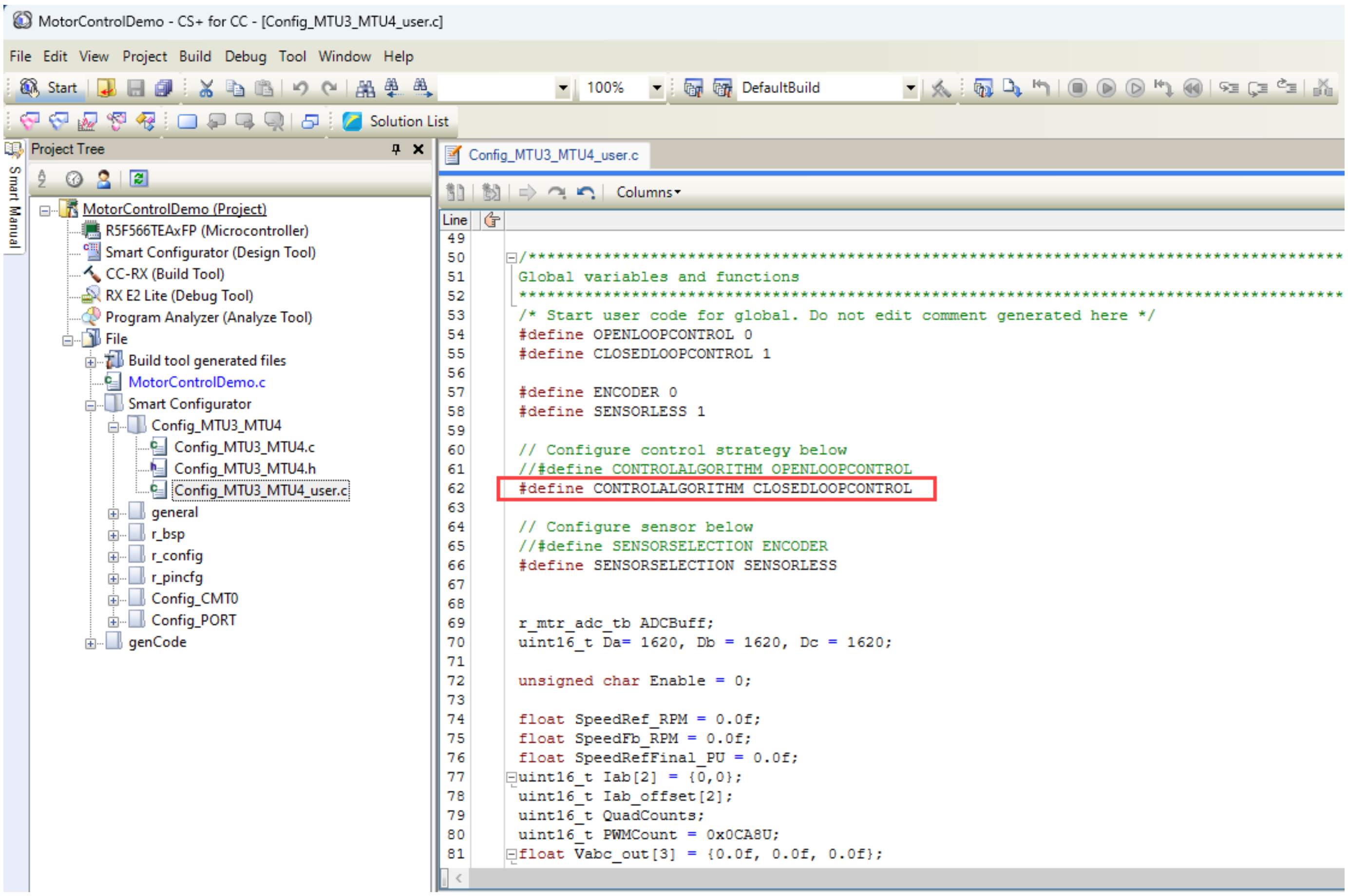


5 In the **Project Tree** panel, expand the folder `File` to open its contents.

Navigate to the folder `Smart Configurator/Config_MTU3_MTU4` and double-click the file `Config_MTU3_MTU4_user.c` to open it in the editor.

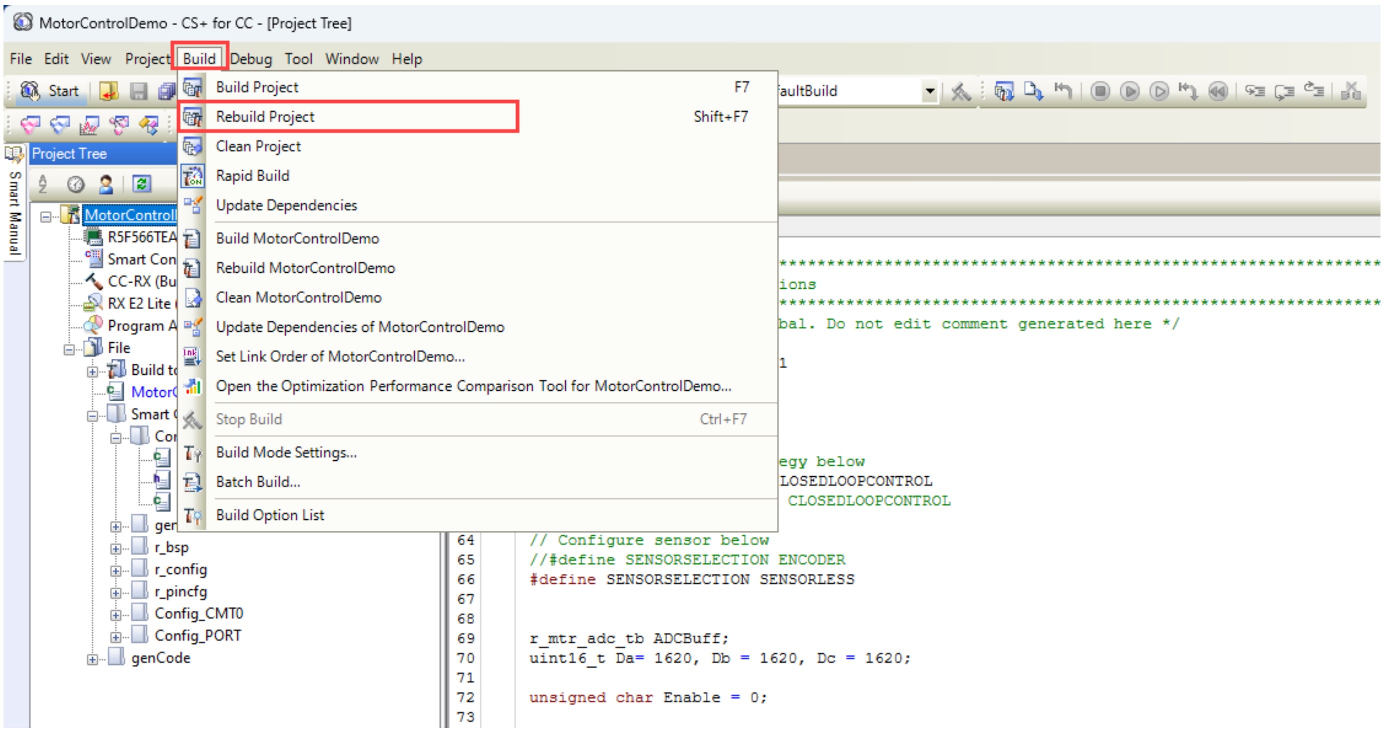


6 Set the macro `CONTROLALGORITHM` to `CLOSEDLOOPCONTROL` as shown in the following figure.

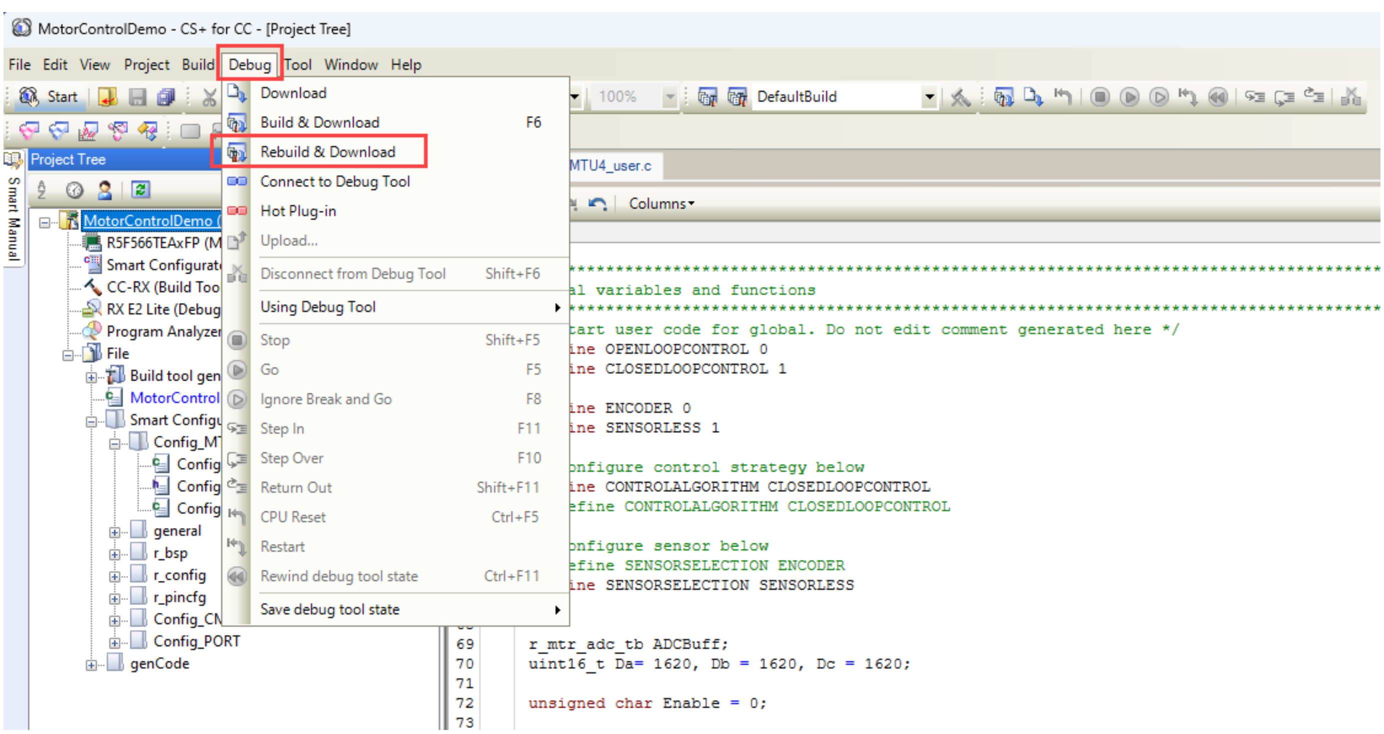


Save the file `Config_MTU3_MTU4_user.c`.

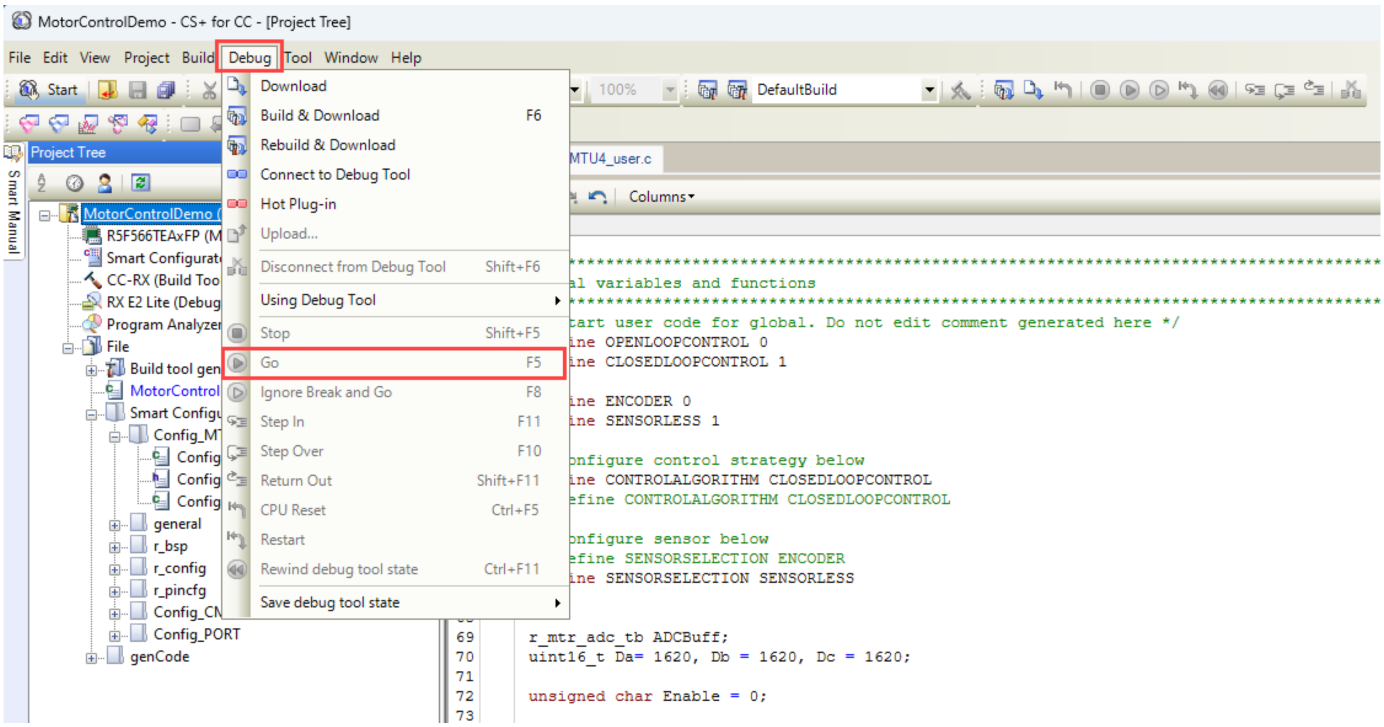
7 In the CS+ software interface, click **Build** > **Rebuild Project** to build the object code for the entire Renesas hardware project containing FOC algorithm and hardware drivers.



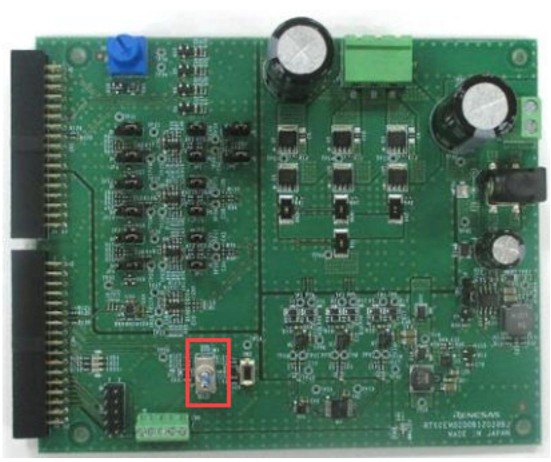
8 In the CS+ software interface, click **Debug** > **Rebuild & Download** to deploy the object code for the FOC algorithm and hardware drivers to the evaluation system for BLDC motor (with RX66T CPU card).



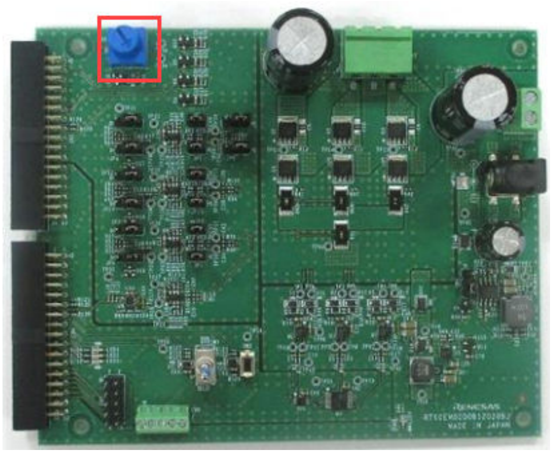
9 In the CS+ software interface, click **Debug** > **Go** to start running the deployed code.



10 On the inverter board, turn the toggle switch to ON position to start running the motor.



11 During code execution on hardware, you can use the following pot (or dial) on the inverter board to change the reference speed for the FOC algorithm.



12 To stop running the motor turn the toggle switch on the inverter board to OFF position.

Note

- You can safely disconnect the evaluation system for BLDC motor (with RX66T CPU card) from the computer after completing step 9.
- After you disconnect the evaluation system from the computer, the deployed code stays on the evaluation system and resumes execution even when you disconnect and reconnect the hardware power supply.